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# Is “Naturalness” Unnatural?

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**Presentation at SUSY ‘06**

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**Introduction:** You may wonder what I’m doing here discussing “Naturalness “and such on a panel with three distinguished theorists, Andre Linde, Lenny Susskind, and Frank Wilczek. I wonder myself. I certainly don’t pretend to do theory on the level of my colleagues, nor even on the level of their beginning students. However, I do know things about the advance of science and I think that some of what passes for the most advanced theory these days is not really science. This is not a comment on any particular work of my colleagues on this panel, but on some of the modern directions of theory. While the formal title of this panel may be Naturalness, it will, I am sure, also include the Cosmological Anthropic Principle, and The Landscape.

I’m sure the other panelists will talk most likely about serious theoretical calculations. I instead will discuss what I see as major problems in what passes for the philosophy behind theory these days. I see no problem if part of the theory community goes off into a kind of metaphysical wonderland, but I worry that they may be leading too many of the young theorists along into the same wonderland. Simply put, it looks to me as if much of what passes as the most advanced theory these days is more theological speculation than it is the development of practical knowledge. It is not necessary to discuss manifolds or dimensional compactification and such things in order to discuss what physics means, and what it has been doing and what it should be doing.

I do have some faded credentials in theory. When I began graduate school, I couldn’t decide whether I wanted to do experiment or theory and so I tried both. My theory practice problem had to do with coulomb excitation of nuclear states, something hot at the MIT cyclotron at the time. I found that what I still call the plumbing of theory, the solving of a problem after you set it up, was less fun than the plumbing of experiments,

actually building things that make measurements to wrestle new facts from the hands of nature. I also came to the conclusion that one could not do both. The world had gotten too complicated for me at least to believe I could make a contribution to both.

I have always believed that an understanding of theory is very important if you are to be a first rate experimenter. They who do not understand where theory is going can only be technicians for the theorists, and while that will probably guarantee that their proposals will get past the funding agencies and the program committees, it doesn't help much in advancing the understanding of how the universe works, which I think is the goal of all of us. I became a semipro theorist for many years doing my own first order, QED calculations. I can only claim amateur standing now but that is all that is needed to understand where theory is headed.

At the beginning I talked of the distinction between theory as theological speculation and as the development of practical knowledge. Theological speculation is the development of models with no testable consequences. Practical knowledge is the development of models with testable and falsifiable consequences (Karl Popper's definition of science). I like to think of progress in physics as coming from changing "why" questions into "how" questions. Why is the sky blue? For thousands of years the answer was that it was an innate property of "sky" or that the gods made it so. Now we know that the sky is blue because of the mechanism that preferentially scatters short-wavelength light.

In the 1950s we struggled with an ever increasing number of meson and baryon resonances; all apparently elementary particles by the standards of the day. Gell-Mann and Zweig produced the quark model which swept away the plethora of particles and replaced them with a simple underlying structure. That structure encompassed all that we had found and predicted things not yet seen. These were seen and the quark model became practical knowledge. Why there were so many states was replaced with how they came to be.

A timelier example might be inflation. It is only slightly older than string theory, and when created was theological speculation, as is often the case with new ideas until someone devises a test. Inflation was attractive because if it were true it would solve the flatness problem. It was not testable at first, but a test was devised that predicted the size and position of the high angular harmonic peaks in the cosmic microwave background radiation. When those were found, inflation moved from being theological speculation to a kind of intermediate state where all that is missing to make it practical knowledge is a mathematically sound microscopic realization.

I think we would all agree that understanding how the universe works is the job of physics. The general trend of the path to understanding has been reductionist. We explain our world in terms of a generally decreasing number of assumptions, equations and constants. Sometimes things have gotten more complicated before they became simpler. Aristotle would have recognized only what we call gravity. As more was learned new forces has to be absorbed; first magnetic, then electric, which turned out to be one - electromagnetic. Radioactivity and the nucleus were found requiring the addition of the weak and strong interactions. Grand Unified theories have pulled the number back down again. Still, the general direction is always toward the reductionist; understanding complexity in terms of an underlying simplicity.

The last big advance in model building came a bit more than 30 years ago with the birth of the Standard Model. From the very beginning it was expected that it, like all its predecessors was an approximation that would be superseded by a better one that would encompass new phenomena beyond the energy range of validity of the standard model. Experiment has found more things that are not accounted for in it; neutrino masses and mixing and dark matter, for example. However, the back and forth between experiment and theory that led to the Standard Model ended. While many new directions were hypothesized, none turned out to have the predicted experimental consequences in the region accessible to experiments, and that brings us to where we are today, looking for something new and playing with such things as naturalness, the Anthropic Principle, and the Landscape.

**Naturalness:** I have asked many theorists to define “naturalness”. I received many variations on a central theme which I would put as follows: a constant that is smaller than it ought to be has to be kept there by some sort of symmetry. If, for example, the Higgs mass is quadratically divergent, invent super-symmetry to make it only logarithmically divergent and keep it small. The price of this invention is 124 new constants which I always thought to be to high a price to pay. Progress in physics almost always is made by simplification. In this case a conceptual nicety was accompanied by an explosion in arbitrary parameters. Experiment has forced a retreat in the expected value of the mass of the lightest super-symmetric particle. However, the LHC starts taking data in 2008 and we will know in a couple of years if there is anything there. If nothing is found, the “natural” theory of super-symmetry will be gone.

An even more interesting example to an amateur like me is the story of the cosmological constant. Standard theory gave it a huge value, so large that the universe as we know it could not exist. If it was not huge, it was assumed by all that it had to be zero. Unlike super-symmetry, there was no specific symmetry that made it zero, but it was expected that one would be found eventually. No one took seriously the possibility of a small cosmological constant until the supernova experiments said that the Hubble expansion seemed to be speeding up. Here, naturalness seemed to prevent any serious consideration of what turned out to be the correct direction.

I do not think that the naturalness concept can be credited with helping Glashow, Iliopoulos, and Maiani develop the GIM mechanism. Naturalness was hypothesized later. Suppressing flavor changing neutral currents required restoring a certain kind of symmetry to the quark sector. They added the charmed quark to restore symmetry in the quark sector to solve the problem, and it was there.

The score card for naturalness is one no, the cosmological constant; one yes, the charmed quark; and one maybe, but still possible, supersymmetry. It certainly doesn’t seem to be a natural and universal truth. Some things are simply initial conditions.

Naturalness may be a reasonable starting point to solve a problem, but it doesn't work all the time and one should not force excessive complications in its name.

**Anthropic Principle:** For more than 1000 years the Anthropic Principle has been discussed, most often in philosophic arguments about the existence of God. Maimonides in the12th century and Aquinas in the 13th used Anthropic arguments to trace things back to what must have been an uncaused first cause, and the only possible uncaused first cause to them was God.

The cosmological Anthropic Principle is of more recent vintage. If you are interested in the evolution of the Anthropic Principle as a tool for use in arguments about cosmology, I refer you to a 700 page book "The Anthropic Cosmological Principle" by John D. Barrow and Frank J Tipler, Oxford University Press, 1986. They are physicists and the book has an introduction by John Wheeler. They start off in their introduction as follows:

> *"Any observed properties of the Universe that may initially appear astonishingly improbable can only be seen in there true perspective after we have accounted for the fact that certain properties of the Universe are necessary prerequisites for the evolution and existence of any observers at all. The measured values of many cosmological and physical quantities that define our Universe are circumscribed by the necessity that we observe from a site where conditions are appropriate for the occurrence of biological evolution and at a cosmic epoch exceeding the astrophysical and biological timescales required for the development of life-supporting environments and biochemistry."*

It is true for example that the fine structure constant has to be close to 1/137 for there to be carbon atoms and carbon atoms are required for us to be here talking about cosmology. You can also derive more constraints on the strong and weak coupling constants from the solar cycle. However, this has nothing to do with **explaining** what physical laws led to this particular value of alpha. An interesting recent paper by Harnik, Kribs, and Perez (arXiv:hep-ph/0604027 4April2006) demonstrates a universe with our

values of the electromagnetic and strong coupling constants, but with a zero weak coupling constant. They show how this can lead to a universe with big-bang nucleo-synthesis, carbon chemistry, stars that shine for billions of years and the potential for sentient observers that ours has. Our universe is not the only one that can support life, and some constants are not anthropically essential.

The Anthropic Principle is an **observation**, not an **explanation**. To believe other wise is to believe that our emergence at a late date in the universe is what forced the constants to be set as they are at the beginning. If you believe that, you are a Creationist. We are here at this and other meetings talking about the big bang, and string theory, and the number of dimensions of space-time, and dark energy, and more. All that the Anthropic Principle says is as you make your theories you had better make sure that alpha is 1/137 for that is a constraint that has to be obeyed in order to agree with experiment. I have a very hard time accepting the fact that some of our distinguished theorists do not understand the difference between observation and explanation, but it seems to be so.

**The Landscape:** String theory was born roughly 25 years ago. Although it needed 10 dimensions to work, the prospect of a unique solution to its equations that allowed the unification of gravity and quantum mechanics was enormously attractive. Regrettably, it was not to be. Solutions expanded as it was realized that there was more than one solution and expanded still further when it was also realized that objects of higher dimension than 1 in this 10 dimensional space (branes) also had to be considered. Today, it seems that there is nearly an infinity of solutions each with different values of fundamental parameters, and there seem to be no relations among them.

What we have is the landscape with a huge collection of potential universes and no way as yet to chose among them. No solution that looks like our universe has been found. No solution that reduces the number of arbitrary things in some of the possible universes has been found. For example it would be a triumph if correlations could be found such as all solutions in the landscape that had a weak coupling anywhere near ours also has a small cosmological constant. No such relationships have been found,

and what we have is a large number of very good people trying to make something more than philosophy our of string theory.  Some, perhaps most, of the attempts do not contribute even if they are formally correct.

Hawking and Hertog in their recent paper “Populating the Landscape: A Top Down Approach” (hep-th/0602091, 10 Feb 2006), start with what they call a “no boundary” approach that *ab-initio* allows all possible solutions.  They then want to impose boundary conditions at late times that allow our universe with our coupling constants, number of non-compact dimension, etc.  This can give solutions that allow predictions at later times, they say.  That sounds good, but it sounds to me an awful lot like the despised fine tuning.  If I have to impose on the landscape our conditions of 3 large space dimension, a fine structure constant of 1/137, etc, to make predictions about the future, there would seem to be no difference between the landscapes and mean field theory with a few initial conditions imposed.

Although their paper sometimes is obscure, they seem to say that their approach is only useful if the probability distribution of all possible alternates in the landscape is strongly peaked around our conditions.  I’ll buy that.

To the Landscape Gardeners I would say calculate the probabilities of alternative universes, and if ours does not come out with a large probability while all others with content far from ours come out with negligible probability, you have no useful contribution to make to physics.  It is not that the landscape model is necessarily wrong, but rather if a huge number of universes with different properties are possible and are also probable, the landscape can make no real contribution other than a philosophic one.  That is Meta-physics, not Physics.

**A Final Hope:**  Over the next decade new tools will come on line that will allow experiments at much higher energy in accelerators.  New non-accelerator experiments will be done on the ground, under the ground and in space.  One can hope for a collection of new clues to a better understand that are less subtle than those we have

so far that do not fit the standard model.  After all, the Hebrews after the escape from Egypt wandered in the desert for 40 year before finding the Promised Land.  It is only a bit more than 30- since the solidification of the Standard Model.